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33.3: Development of Super-High-Image-Quality Vertical-Alignment-Mode LCD

K. Ohmuro, S. Kataoka, T. Sasaki, Y. Koike
Fujitsu Ltd., Atsugi, Japan

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Abstract

We have developed a vertically aligned LCD (VA-LCD) which offers the same image quality of a CRT. This display has a super-wide viewing angle of over 70° in all directions, a fast response (< 25 ms), and a high contrast ratio of over 300. The VA-LCD has been successfully implemented by optimizing a vertically aligned mode with a domain-divided structure and an optical compensator. We describe the optimization of a panel parameter and an optical compensator by computer simulation, and show the experimental results. We realized a 10.4-inch-diagonal VGA full-color prototype VA-LCD with super high quality.

1. Introduction

Currently, the market for LCDs is increasing rapidly. However, the viewing angle and contrast ratio of LCDs are still insufficient for their use in large-screen products. For high image quality, these characteristics need to be improved.

Recently, many methods for wide viewing angle TFT-addressed LCDs have been proposed. These methods use DDTN mode,[1] IPS mode,[2] as well as other optically compensated modes : OCB,[3] Compensator Film,[4] and D-HAN.[5] We had already realized a DDTN-LCD in 1992.[6] To further improve the viewing angle, we adopted VA mode for a high quality LCD [7] which has a pure black image at the off state. The VA mode itself is very old. Recent improvements in materials which include the liquid crystal and alignment layers, have made application of this mode possible in TFT-LCDs.

First of all, the optimization of the panel parameter and optical compensator condition in the VA mode was examined by simulation. Then the simulation results and the characteristics of VA test cells were compared, including the reasons for a wide viewing angle, a high-speed response, and a high contrast ratio. Finally, the high image quality was proved using a 10.4-inch-diagonal VGA full-color prototype VA-LCD.

2. Simulation

Figure 1 shows the panel structure of the adopted VA mode. In this panel structure, the viewing angle and the transmittance when Δnd ($\Delta n = n_e - n_o$, d are cell gap) is changed are shown in Figure 2. We found that the viewing angle increases as Δnd decreases, and that the transmittance decreases to less than $\Delta nd = 0.3$ µm. The method of adding a negative retardation film equal to Δnd to improve the viewing angle has been reported.[8] However, in this method, the viewing angle

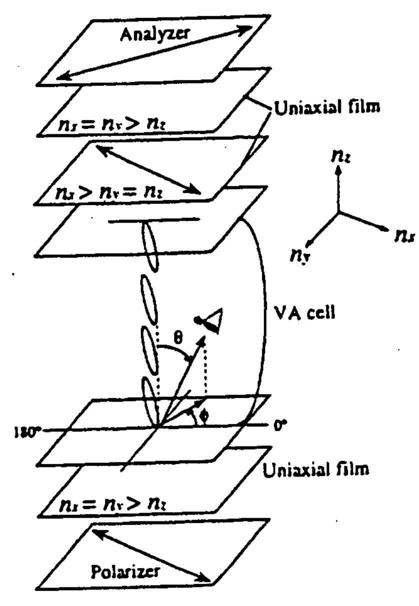

Figure 1. Panel structure of adopted VA-LCD.

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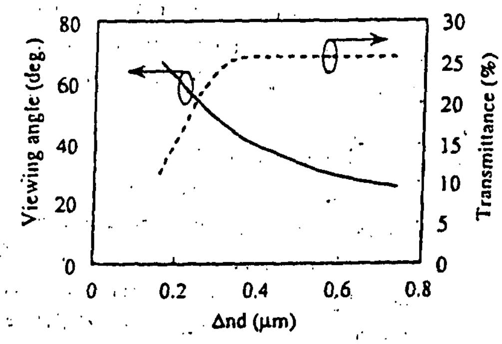


Figure 2. Dependence of viewing angle and transmittance on Δnd.

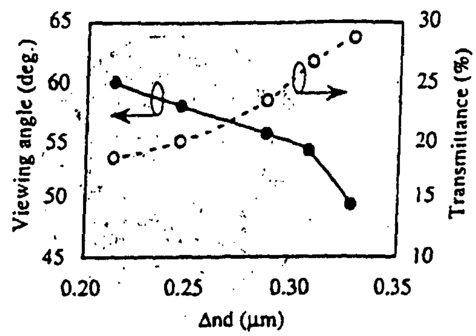


Figure 4. Dependence of viewing angle and transmittance on Δnd.

improvement is not enough.

Therefore, we added a uniaxial positive retardation film on a uniaxial negative retardation film. This optical compensation method decreases the transmittance of the off state in the azimuth of $\phi = 0°$ which is angled at $\phi = 45°$ to the polarizer or analyzer absorption axis. Figure 3 shows the transmittance characteristics of the off state when a negative and a positive retardation film are added. The transmittance at $\phi = 90°$ decreases, mostly when the positive retardation is about 50 nm.

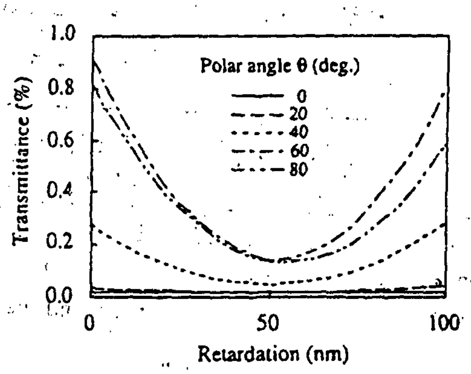


Figure 3. Dependence of retardation of a positive compensator.

3. Results and Discussion

3.1 Viewing angle characteristics

The VA panel uses a vertical alignment layer and a dielectrically negative LC mixture. The fabrication process of the VA cell is the same as for a conventional TN cell. Figure 4 shows the optical characteristics of the VA cell when Δnd is changed. It is clear that as the cell gap decreases, the viewing angle increases according to the decrease in transmittance. This almost corresponds the simulated results shown in Figure 2. Figure 5 shows the viewing angle characteristics of the VA cell (Δnd=0.25 μm) and a conventional TN cell. We found that the viewing angle (C.R. > 10) of the VA cell is much wider than for a conventional TN cell. In particular, the vertical characteristics are much better than a conventional TN cell.

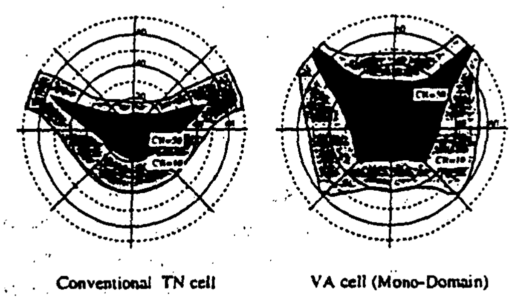


Figure 5. Viewing angles of a conventional TN cell and aVA cell.

Figure 6 shows that the viewing angle characteristics of the VA panel using an optical compensator are improved greatly. In addition, we adopted a domain-dividing structure for the VA cell and succeeded to improve the viewing angle characteristics in all directions. Figure 7 shows the viewing angle of a domain-divided VA cell. We have achieved a super-wide viewing angle (>70°) in all directions.

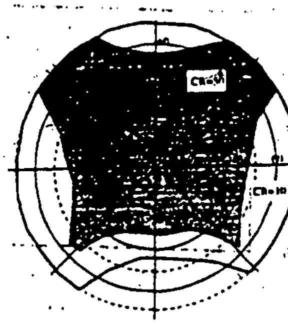


Figure 6. Viewing angles of a compensated VA cell.

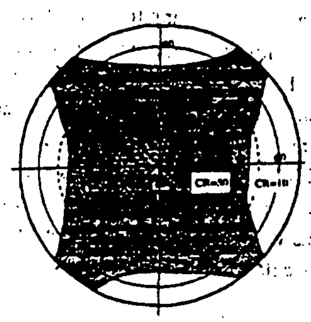


Figure 7. Viewing angles of a domain-divided VA cell.

3.2 Response characteristics

The experimental results showed that the response speed of the VA cell is higher in proportion to the decrease in the cell gap. However, if we adopt a domain-dividing structure, the response speed will depend largely on the domain-divided pattern (Table 1). We can obtain the highest response speed by adopting a domain-divided pattern (a).

3.3 High contrast ratio

Basically, the contrast ratios of TN mode and of VA mode are expected to be the same. However, it is different in a real cell. Figure 8 shows the difference in the light-leakage of the vertically aligned cell (VA cell) and the homogeneous aligned cell (HA cell) with crossed polarizers. In VA mode, we found that there is very little light-leakage around the spacers compared with that in homogeneous aligned mode. Because there is less distortion of the liquid crystal molecules around the spacers in VA mode than in homogeneous aligned mode, the VA cell has a higher contrast ratio.

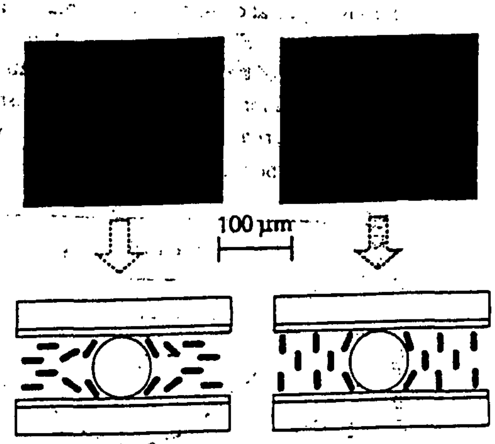
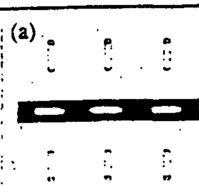
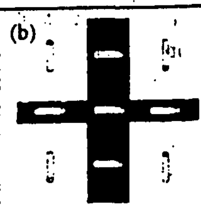
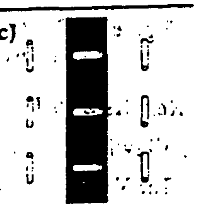


Figure 8. Light-leakage around spacers.

Table1. Response characteristics of domain divided VA-cells.

	(a)	(b)	(c)
Domain pattern			
Ton (ms)	8	42	209
Toff (ms)	5	5	5

4. 10.4-Inch Prototype VA-LCD

The VA-LCD panel was fabricated using a conventional TFT substrate (10.4-inch VGA) and a CF substrate. The viewing angle characteristics of this panel are shown in Figures 9 and 10. It is obvious that the VA-LCD has very wide viewing angle characteristics with no gray-scale inversion. Table 2 shows the specifications of a 10.4-inch VA-LCD. It is clear that the VA-LCD has super-wide viewing angle characteristics, a high-speed response, and high contrast ratio.

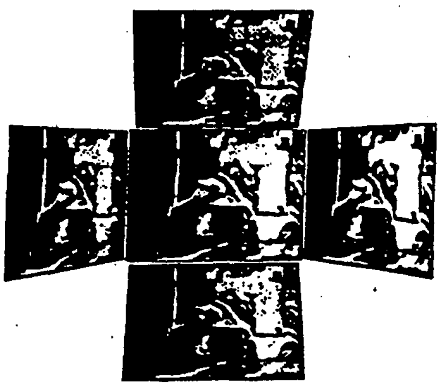
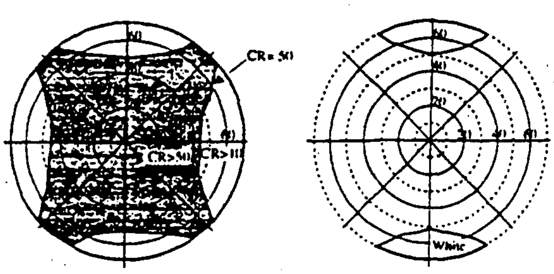


Figure 9. Display characteristics of a VA LCD.

This figure is reproduced in color on page 1135.

Table 2. Specifications of 10.4-inch VA-LCD.

Display area	10.4-inch-diagonal
Viewing angle (CR>10)	> 70° all directions
Contrast ratio	> 300
Response time	< 25 ms
Driving voltage	5 V



Iso-contrast Inversion (8 Levels)

Figure 10. Viewing angle characteristics of a VA-LCD.

5. Conclusion

We have developed a large-area, high-image quality LCD which is almost equal to a CRT, by combining the domain-dividing technique with the optimized vertical alignment mode. We believe that this large-area panel can be used as a replacement for the CRT and the technology we have developed will become important for future large-area LCDs.

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